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Local Column Density Distribution Function from HI selected galaxies.

Emma Ryan-Weber

University of Melbourne, VIC 3010 Australia

Rachel Webster

University of Melbourne, VIC 3010 Australia

Lister Staveley-Smith

Australia Telescope National Facility, CSIRO, PO Box 76, Epping, NSW 1710, Australia

Abstract. The cross-section of sky occupied by a particular neutral hydrogen column density ($N_{\rm HI}$) provides insight into the nature of Lyα absorption systems. We have measured this column density distribution at z=0 using 21-cm HI emission from a blind survey. A subsample of HI Parkes All Sky Survey (HIPASS) galaxies have been imaged with the Australia Telescope Compact Array (ATCA). The contribution of low HI mass galaxies ($10^{7.5}$ to 10^{8} $M_{\odot}$) is compared to that of M$_{*}$ (10^{10} to $10^{10.5}$ $M_{\odot}$) galaxies. We find that the column density distribution function is dominated by low HI mass galaxies in the range $3\times10^{18} < N_{\rm HI} < 2\times10^{20}$ cm^{-2}. This result is not intuitively obvious. M$_{*}$ galaxies may contain the bulk of the HI gas, but the cross-section presented by low HI mass galaxies ($10^{7.5}$ to 10^{8} $M_{\odot}$) is greater at moderate column densities. This result implies that moderate $N_{\rm HI}$ Lyα absorption systems may be caused by a range of galaxy types and not just large spiral galaxies as originally thought.

1. Introduction

Lyman α (Lyα) absorption systems provide a powerful probe into the distribution of baryonic matter in the Universe across the stages of galaxy evolution. The column density distribution function, $f(N_{\rm HI})$ is one way to characterise this distribution. $f(N_{\rm HI})$ is defined as the probability of intersecting a particular column density along a random line-of-sight per unit distance. It describes the cross-sectional area of sky occupied by a particular column density at a given redshift. Traditionally $f(N_{\rm HI})$ is measured by Lyα absorption in the continuum spectra of background QSOs. At high redshift $f(N_{\rm HI})$ is well measured over 10 orders of magnitude in column desnity (eg. Tyler 1987; Petitjean et al. 1993). At low redshift, since the Lyα transition is in the UV and the occurrence of high column density absorbers is low, we have measured the neutral hydrogen column density distribution using 21-cm HI emission. The purpose of this investigation is to calculate $f(N_{\rm HI})$ using a range of galaxy HI masses and determine their contribution to the column density distribution function.

In the last few years it has become apparent that Damped Lyman α (DLyα) systems are not necessarily caused by the HI disks of large spiral galaxies (eg. Rao & Turnshek 1998; Bowen, Tripp, & Jenkins 2001). Regardless of this, the paradigm of large spirals being responsible for the majority of the cross-section of column densities $N_{\rm HI} > 10^{19}$ at z=0 remains.

2. Motivation and Justification

According to Dickey & Lockman (1990) "The agreement between ultraviolet and radio estimates of $N_{\rm HI}$ is excellent and somewhat astonishing, considering that the angular resolution, experimental techniques, and telescopes differ in all respects". This statement refers to a comparsion of high latitude Galatic HI 21-cm measurements compared with Lyα absorption towards distant stars (in the same direction) in the range $10^{20} < N_{\rm HI} < 10^{21}$ cm^{-2}. One concern remains that high column density gas may clump on scales less than the beam size. This has been addressed by Rao & Briggs (1993) in their calculation of the contribution of high $N_{\rm HI}$ gas to the HI mass function (which is not affected by beam size) compared with the integral of mass from the $f(N_{\rm HI})$ cross-section. They find the integral of mass in $f(N_{\rm HI})$ is equivalent to that from the mass function at high $N_{\rm HI}$. They concluded that any high $N_{\rm HI}$ column density gas missed due to a large beam size is negligible.

The advantages of using 21-cm observations to measure column density, rather than Lyα absorption are:

- For z$\lesssim$1.65, Lyα requires space based observations.
- The space density of Lyα absorbers at low redshift is small. Indeed, Rao & Briggs (1993) estimated that 1000 random sight lines would be required to provide 10$\pm$3 DLyα systems. According to Rao and Turnshek (2000) 23 DLyα systems are known at z<1.65.
- Significant evolution of the column density distribution is still expected between z$\sim$1 and z=0, so it is important provide an anchor point at z=0.
- Foreground galaxies may hinder QSO identification. Extinction and reddening by dust in galaxies means that QSOs may be preferentially found away from galaxies (0striker & Heisler 1986).

3. Comparison to previous work

Previous calculations of the column density distribution function from 21-cm emission has published by Rao & Briggs (1993) and Zwaan, Verheijen, & Briggs (1999). The study by Rao & Briggs used Arecibo observations of 27 large spiral galaxies. Zwaan et al. on the other hand used synthesis observations of Ursa Major cluster members. The advantage of the method presented here is that a range of HI mass galaxies are including in the sample from the whole sky, rather than a galaxy cluster, which are known to HI deficient (eg. Solanes et al. 2001). The benefit of using a galaxy cluster is that the spatial resolution is the same in each map. We have preserved this feature by selecting galaxies within a tight velocity range. We have also used an HI mass function for normalisation which is more appropriate than an optical luminosity function, used by the two previous studies.

4. Observations

Galaxies for this study were selected from the HI Parkes all sky survey (HIPASS) Bright Galaxy Catalogue (Koribalski, 2000). HIPASS is a blind survey for HI covering the entire southern sky, thus providing a complete HI selected sample. The 3σ HI mass limit of HIPASS is $10^6 D^2_{Mpc} M_\odot$ and the 3σ HI column density limit is 4×10^{18} cm^{-2}. To provide a representative range of HI mass, 36 galaxies were chosen randomly to fill six half decade HI mass bins from $10^{7.5}$ to $10^{10.5}$ $M_\odot$. Galaxies were restricted to those with helocentric velocities in the range 500 to 1700 km s^{-1} so that the spatial resolution across the sample remained comparable across the sample. The gridded FWHP beamwidth of HIPASS is $15.5'$ which means that most galaxies are poorly resolved. Since the HIPASS maps provide a column density spread over the entire beam area, higher resolution mapping was required to measure distribution of column desnity. Each galaxy was observed with the Australia Telescope Compact array (ATCA) with a minimum FWHM beam size of $30''$. The typical 3σ HI column density limit for the observations was $\sim 3 \times 10^{18}$ cm^{-2}.

5. Data Analysis

The brightness temperature measured for each pixel in the synthesis map, T$_b$ is converted to column density by the relationship:

$$N_{\rm HI} = 1.823 \times 10^{18} \int T_b dv \quad {\rm cm}^{-2}. \tag{1}$$

This calculation assumes that the gas is optically thin. Dickey & Lockman (1990) used typical Galactic HI parameters (T$_s \sim 50$K and $\Delta v \sim 10$km s^{-1}) to show that the optical depth is greater than 1 for $N_{\rm HI} > 10^{21}$ cm^{-2}. Consequently the column density may be underestimated as $N_{\rm HI}$ approaches 10^{21} cm^{-2}. The column density distribution function is then calculated by

$$f(N_{\rm HI}) = \frac{c}{H_0} \frac{\phi \Sigma(N_{\rm HI})}{dN_{\rm HI}}, \tag{2}$$

where $\Sigma(N_{\rm HI})$ is the area in Mpc^2 occupied by a particular column density, in the range $N_{\rm HI}$ to $N_{\rm HI} + dN_{\rm HI}$. The function is normalised by the space density ϕ taken from a HIPASS HI mass function (Kilborn, 2000). The HI mass function has a faint end slope of $\alpha = 1.52$ and an characteristic HI mass of $M_* = 1.14 \times 10^{10} M_\odot$. An H_o of 75 km s^{-1} Mpc^{-1} is adopted to match that of the HI mass function and a value of $dN_{\rm HI} = 0.2$ dex is used throughout.

The distance to each galaxy was calculated assuming the velocity represents the Hubble flow and corrected for Local Group velocity. Uncertainty in the distance is a large source of error; it affects both $M_{\rm HI}$ and the area function, $\Sigma(N_{\rm HI})$. $f(N_{\rm HI})$ is plotted in Figure 1 with a power law fitted with the form $f(N_{\rm HI}) = BN_{\rm HI}{}^{-\beta}$. From the figure it is evident that low H I mass galaxies dominate $f(N_{\rm HI})$ at column densities in the range 3×10^{18} to 2×10^{20} cm^{-2}. At the DLyα cutoff of 2×10^{20} cm^{-2} both mass types contribute equally. For $N_{\rm HI} > 2 \times 10^{20}$ cm^{-2}, M_* galaxies dominate the column density distribution function.

6. Discussion

From the H I mass function we know that galaxies with $10^6 < M_{\rm HI} < 10^8$ $M_\odot$ contribute only 6% of the total H I mass density at z=0. Indeed most of the H I mass in the local Universe is contained in galaxies with $10^9 < M_{\rm HI} < 10^{10.25}$ $M_\odot$ (Kilborn, 2000). Even though their contribution to the overall H I mass density is minimal, the cross-sectional area presented by low H I mass galaxies for moderate column densities is significant. This result is interesting as it is not intuitively obvious. The space density of low H I mass galaxies is sufficient to push their cross-sectional area at moderate $N_{\rm HI}$ above that of M_* galaxies. The morphology of the galaxies in the lowest mass bin are generally Irregular type. In contrast to those in the M_* mass bin which are generally Early type spirals.

This result has implications for the interpretation of the column density distribution function at all redshifts. If systems with $M_{\rm HI} = 10^{7.5}$ $M_\odot$ are responsible for a significant fraction of the moderate column density cross-section at low redshift, they may also cause a significant fraction of absorption systems at high redshift. As noted above, the typical morphology of these systems is Irregular. Normal spiral galaxies are known to decrease their star formation rate (SFR) with time, yet recent evidence suggests that Irregular galaxies experience an increasing SFR with time (Xu et al. 1994). Therefore galaxies associated with moderate $N_{\rm HI}$ Lyα absorption systems at high redshift may have been missed due to low optical luminosity.

7. Conclusion

We have shown that at z=0, the contribution of low H I mass galaxies to the column density distribution function is greater than M_* galaxies for $N_{\rm HI}$ up to the DLyα cutoff. This result implies that moderate $N_{\rm HI}$ Lyα absorption systems may be caused by a range of galaxy types and not just large spiral galaxies as originally thought.

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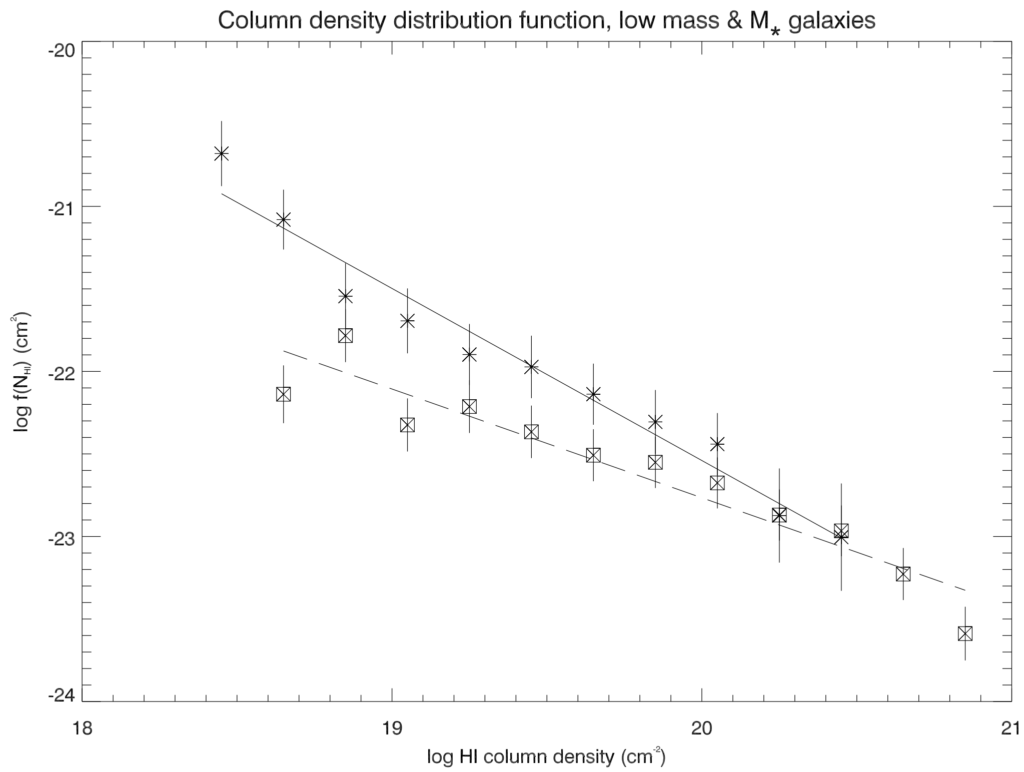

Figure 1. Column density distribution function at z=0 for two different H I mass galaxy types. $f(N_{\rm HI})$ from low H I mass galaxies ($10^{7.5} < M_{\rm HI} < 10^{8}\ M_{\odot}$) are represented by the solid line and asterisk data points. $f(N_{\rm HI})$ from M_{*} galaxies are represented by the dashed line and square data points.

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